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Original Research

# Contrasting Effects of Long-Term Fire on Sagebrush Steppe Shrubs Mediated by Topography and Plant Community☆

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ABSTRACT

The role of fire in restoration of sagebrush plant communities remains controversial mainly because of paucity of information from long-term studies. Here, we examine 15-year post-fire responses of big sagebrush (Artemisia tridentata ssp wyomingensis) and broom snakeweed (Gutierrezia sarothrae), the two most abundant native shrubs at the John Day Fossil Beds National Monument, a protected area in north-central Oregon, USA. Fire effects were studied along gradients of topography and community type through time post-burn. Community types were distinguished as brush, plots dominated by big sagebrush and woodland, plots with a significant presence of Western juniper (Juniperus occidentalis) trees. Fire reduced big sagebrush cover in brush plots up to 100% and in woodland plots up to 86%. Broom snakeweed cover declined by 92% and 73% in brush plots and woodland plots, respectively. Big sagebrush did not show signs of recovery 15 years after burning regardless of topography and community type while broom snakeweed populations were clearly rebounding and prospering beyond pre-burn levels. Our results showed that an area initially dominated by big sagebrush (cover of big sagebrush 10-20%, cover of broom snakeweed 2-4%) dramatically shifted to an area dominated by broom snakeweed (cover of big sagebrush < 1%, cover of broom snakeweed 5%) in brush-dominated plots. Our results indicated that brush-dominated plots at lower elevation and southern exposures are the least post-fire resilient. We also observed a declining population of big sagebrush on unburned areas, suggesting the lack of post-fire recovery on burned areas was perhaps a result of low seeding potential by extant populations. Although more years of observation are required, these data indicate that recovery time, the encroachment of opportunistic competing shrubs, and the initial condition of vegetation are essential considerations by land managers when prescribing fire in big sagebrush communities.

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## Introduction

The sagebrush (*Artemisia* sp.) steppe is one of the largest and most threatened ecosystems in North America (Davies et al., 2011). These systems have declined from 25 million ha pre-European settlement to about 13 million ha (Miller et al., 2011; Chambers et al., 2014a). The loss of sagebrush steppe has been primarily due to past land management approaches resulting in overutilization of forage species, invasion by annual grasses and woody species, declines in species diversity, and changes in fire frequency (Davies et al., 2011; Svejcar et al., 2014).

Fire is a common disturbance in sagebrush communities (Miller and Heyerdahl, 2008; Ellsworth et al., 2016). Yet the historic fire return interval, fire behavior, and ultimately fire effects have been altered by changes to preburn plant communities as a result of late 19th and early 20th century overgrazing, active fire suppression, annual grass invasion, and conifer encroachment (Davies et al., 2011; Chambers et al., 2014b). In addition, increased temperatures and earlier springs associated with climate change are correlated with increased wildfire frequency and total burned area throughout the western United States (Westerling et al., 2006; Svejcar et al., 2014).

Increased fire size and frequency in conjunction with burn pattern homogeneity (Miller and Eddleman, 2001; Miller and Heyerdahl, 2008) create barriers to reestablishment for native sagebrush steppe species such as *Artemisia tridentata* after fire. *A. tridentata* is a nonsprouter that establishes by seed and is entirely dependent on neighboring unburned sites, to reestablish on a burned site (Miller et al., 2013). The long-term recovery of *A. tridentata* can be variable depending on subspecies (Lesica et al., 2007). *A. tridentata*

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ssp. *vaseyana* in Montana has recovered in around 30 yr to preburn levels (Lesica et al., 2007; Mata-Gonzalez et al., 2007; Mata-Gonzalez et al., 2008), but the few long-term reports that exist for ssp. *wyomingensis* seem to indicate a longer recovery time. Lesica et al. (2007) and West and Yorks (2002) concluded that after 18 − 25 yr post burn the recovery of *A. tridentata* ssp. *wyomingensis* is low to negligible. In addition to its slow recovery after fire, *A. tridentata* ssp. *wyomingensis* communities are generally regarded to exhibit low resilience to disturbance and low resistance to invasion (Chambers et al., 2007; Miller et al., 2013; Chambers et al., 2014a). The slow recovery and low resilience of degraded sagebrush ecosystems may be responsible for declines in populations of sagebrush-obligate wildlife species, such as the Greater sage-grouse *(Centrocercus urophasianus)* (Beck et al., 2009; Dinkins et al., 2014).

*Gutierrezia sarothrae* Pursh (broom snakeweed) is also a native sagebrush steppe species that, in contrast to *A. tridentata,* can be a postfire sprouter (although a weak one) (Miller et al., 2013), tends to increase its population in response to fire, and remains a dominant shrub component under disturbance (Ralphs and McDaniel, 2011). *G. sarothrae* is a short-lived species that thrives under disturbance, can be toxic to livestock, and is typically dominant on rangelands in poor condition (Thacker et al., 2008). This species is relatively drought tolerant and able to adapt to variations or pulses in soil water conditions (Wan et al., 2002), and once established in a plant community it can be persistent (Thacker et al., 2008).

Prescribed fire remains a controversial tool in shrubland management around the world (van Wilgen et al., 2010; Dalgleish et al., 2015; Ellsworth et al., 2016). Thus understanding both short- and long-term fire effects on shrubland ecosystems is important for conservation efforts and sustainable management. It is especially important to understand the response to fire of native shrubs such as *A. tridentata* and *G. sarothrae* in the sagebrush steppe because of the different functions these species display within vast ecological communities of North America. *A. tridentata* is a foundational long-lived species in sagebrush steppes and plays a fundamental role in the ecosystem's structure and function (Davies et al., 2011; Rodhouse et al., 2014). In contrast, *G. sarothrae* is an opportunistic species that responds rapidly to increased resource availability (Ralphs and Sanders, 2002).

In North America, studies of short-term (< 5 yr) responses of plant species to fire are relatively abundant within the literature, in contrast to long-term (> 10 yr) responses (Miller et al., 2013). Furthermore, often the currently available long-term research utilizes multiple burn sites of different ages in different locations instead of repeated measures on the same site (substitute space for time), lacks unburned control plots, and does not have preburn plant community data (Miller et al., 2013). Information on long-term species responses are needed to bridge gaps between scientific research and management applications (Chen et al., 2013).

Responses of vegetation to fire are likely mediated by topographical conditions because factors such as exposure and elevation modify soil moisture, soil nutrients, and temperatures (Mata-Gonzalez et al., 2002), and thus the degree of resilience of plant communities (Rodhouse et al., 2014). Other factors being equal, plants are more likely to rebound after fire in cooler and moister soils than in warmer and dryer soils (Miller et al., 2013). In addition, the effects of fire on individual species may vary for different community types because species interactions may temper or enhance species responses to disturbance (Engel and Abella, 2011). The objective of this study was to characterize long-term (15-yr) responses of *A. tridentata* subsp. *wyomingensis* and *G. sarothrae,* two important and functionally contrasting native shrubs of the North American sagebrush steppe, to fire, topographical variation, and community type using data with repeated measures on plots through time, unburned controls, and preburn community data. Our study area has low precipitation and mainly aridic soils (see descriptions later), and thus plant community resilience is expected to be inherently low (Chambers et al., 2014b). We hypothesized that the two species of study would show differential recovery responses to fire through time and that topography and community type would influence their responses.

## Materials and Methods

### Study Site

The study site is part of the John Day Fossil Beds National Monument (hereafter, JDFBNM), which is a protected area managed by the National Park Service of the United States located in north-central Oregon, United States. The site is part of the John Day River Valley and a subunit of the Columbia River Plateau physiographical region (USDI National Park Service, 2009). This study was conducted in the Sheep Rock management unit of the JDFBNM, 14 km west of Dayville, Oregon, United States (Fig. 1). The Sheep Rock unit encompasses 3 648 ha and has a history of both sheep and cattle grazing from 19th century Euro-American settlement of the John Day River Valley to the establishment of the JDFBNM in 1975 (Erixson et al., 2011). The study area ranges in elevation from 610 m at the river valley bottom to 1 370 m at the top of the steep hills. The Sheep Rock unit is semiarid with average annual precipitation of approximately 270 mm. Precipitation falls primarily as rain from November to June with peaks in May and November. From 1999 to 2014, the years of this study, 2010 was the wettest yr and 2002 was the driest yr with 362 mm and 186 mm of precipitation (Fig. 2). Soils of the study area are generally aridic, and most of the study plots are located within the following Natural Resource Conservation Service (NRCS) ecological sites: JD Droughty South 9-12 PZ, JD Droughty North 9-12PZ, JD North 9-12 PZ, and JD Loamy 9-12 PZ.

There are 52 plant associations, primarily defined by geographic variability within the Sheep Rock unit (Erixson et al., 2011). Upland woodlands are dominated by the tree *Juniperus occidentalis* Hook (western juniper) and an understory of native grasses and shrubs. Hill slopes and alluvial fans are primarily dominated by the shrubs *A. tridentata* subsp. *wyomingensis* and *G. sarothrae,* as well as encroaching *J. occidentalis*. Downslope, grasses such as *Pseudoroegneria spicata* (Pursh) A. Löve (bluebunch wheatgrass) and *Poa secunda* J. Presl (Sandberg bluegrass) are dominant. Annual grasses including *Bromus tectorum* L. (cheatgrass) and *Taeniatherum caput-medusae* (L.) Nevski (medusahead) are widely dispersed throughout the JDFBNM but are concentrated on southern exposures and flat ground (Rodhouse et al., 2014). Throughout the whole JDFBNM area the most common shrub species are *A. tridentata* subsp. *wyomingensis* and *G. sarothrae.*

### Data Collection and Experimental Design

Study plot locations were selected using restricted random sampling. If a potential plot location exceeded 60% slope, it was excluded. Experimental plots were established on areas with different exposure and slope. Our plots were located in areas dominated by *A. tridentata* ssp. *wyomingensis* but some had a significant component of *J. occidentalis.* Thus plot locations were differentially identified as 1) brush plots, those that had fewer than 10 *J. occidentalis* trees per ha and 2) woodland plots, those that had more than 10 *J. occidentalis* trees per ha (Reed-Dustin et al., 2016). The total area of *A. tridentata* or *J. occidentalis* dominant land within a given burn unit was divided into equal-sized polygons corresponding to the desired number of plots of each community type. A single plot was randomly located within each polygon.

A total of 37 plots were established, 21 brush plots and 16 woodland plots (Table 1). Of the 21 brush plots, 5 were unburned controls. Of the 16 woodland plots, 8 were unburned controls. The burned and unburned plots were randomly obtained across five prescribed burn areas and burning took place in the fall (early September to early October) of the following yr: 1999 (6 brush plots, 5 woodland plots); 2001 (6 brush plots, 3 woodland plots); 2002 (3 brush plots, 3 woodland plots); 2004 (3 brush plots, 3 woodland plots); and 2005